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Reaction Times of Preschool Children on the Ruler Drop Test: A Cross-Sectional Study With Reference Values

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Abstract

Reaction time (RT) tasks assess several brain functions, and a slow RT can be due to various brain diseases, disorders, and acquired conditions. This study examined age and gender differences in RTs of Spanish preschool children on the ruler drop test (RDT) and presents norm-referenced results. Participants were 3,741 children (1,845 girls and 1,896 boys; mean [M] age = 55.93, standard deviation [*SD*] = 11.14 months; M body mass index = 15.94, *SD* = 1.91 kg/m^2), selected from 51 schools in southern Spain. We measured RT with the RDT, and we collected both right- and left-hand data. We expressed normative mean RDT values of both hands according to gender and age in percentiles. Based on mean RDT scores, girls exhibited a poorer performance than boys aged 4 years ($p = .032$, Cohen's $d = -0.122$) and 5 years ($p = .001$, Cohen's $d = -0.194$). For the whole group, RDT performance was faster with increased age, from the age of five years.

Keywords

early childhood, fitness, health, reaction time

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Introduction

The preschool age is characterized by significant changes in the acquisition of fundamental motor skills and nervous system maturation (Tanaka, Hikihara, Ohkawara, & Tanaka, 2012). The development of motor competence during infancy and childhood is influenced by the individual child's growth and morphological, physiological, and neuromuscular characteristics (Venetsanou & Kambas, 2009). The mastery of fundamental motor skills contributes to children's physical, cognitive, and social development and is essential for an active lifestyle (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). Reaction time (RT), the speed of movement, and agility are some components of motor skills related to fitness (Moradi & Esmaeilzadeh, 2015). RT is the measure of time taken to respond, from the onset of a "Go" signal until a response is made.

Motor-cognitive response time is expressed as RT, which represents both the speed of information processing and the motor response of coordinated peripheral movements (Mishra, Dasgupta, Mohan, Aranha, & Samuel, 2018). RT can be assessed in young children to evaluate developmental changes and individual differences in sustained attention and organization of behavior (Weissberg, Ruff, & Lawson, 1990). Moreover, RT tasks assess several brain functions, such as different attentional processes (Stuss et al., 2005), interhemispheric transfer, age-related changes in cognition (Anstey et al., 2007), cognitive flexibility (Hillman et al., 2014), and motor and cognitive processing speed (Aranha, Moitra, et al., 2017). Simple RT measures correlate significantly with the measures of general intelligence (*g* factor) and are considered elementary measures of cognition (Woodley, Te Nijenhuis, & Murphy, 2014).

A slow RT can result from various brain diseases, disorders and acquired conditions that affect white matter conduction, gray matter neurotransmission, and efficiency of cognitive neural networks (Klotz, Johnson, Wu, Isaacs, & Gilbert, 2012). Therefore, RT deficits have been well demonstrated in children with attention deficit hyperactivity disorder (ADHD; Sjöwall, Roth, Lindqvist, & Thorell, 2013), developmental coordination disorder (DCD; Gama, Ferracioli, Hiraga, & Pellegrini, 2016; Johnston, Burns, Brauer, & Richardson, 2002), dyslexia (Kaltner & Jansen, 2014), and autism spectrum disorder (ASD; Herrero & Crocetta, 2015). Poor RT has also been associated with childhood obesity and high body mass index (BMI) values (Gentier et al., 2013; Skurvydas et al., 2009). Conversely, a high level of moderate and vigorous physical activity has been associated with improved RT performance in children (Syväoja, Tammelin, Ahonen, Kankaanpää, & Kantomaa, 2014).

There are only a limited number of studies that have correlated physical and motor fitness with growth and maturity (Malina & Katzmarzyk, 2006), particularly on RT in preschool children, as most studies of RT have been conducted in children over six years of age (Aranha, Saxena, et al., 2017; Madsen et al., 2011; Manna, Pan, & Chowdhury, 2014; Tamnes, Fjell,

Westlye, Ostby, & Walhovd, 2012). Moreover, there is limited information about the reliability and validity of fitness and motor tests in preschool children (Ortega et al., 2015), though reliable measures of fitness and motor tests are necessary in order to investigate the relationship between physical fitness and health in this population (Latorre Román et al., 2015; Ortega et al., 2015).

RT is typically assessed using computerized neuropsychological testing software (Baisch, Cai, Li, & Pinheiro, 2017; Moradi & Esmaeilzadeh, 2017). However, high cost and requirements for professional management in estimating RT make this method inapplicable in a school setting. A simple, less expensive measure of RT that can be used to replace the computer assessment is the traditional ruler drop test (RDT) and, although the RDT measures RT plus movement time, it continues to be an acceptable means of measuring simple RT (Del Rossi, Malaguti, & Del Rossi, 2014). The RDT has acceptable reliability and criterion validity (Aranha, Sharma, Joshi, & Samuel, 2015; Eckner, Whitacre, Kirsch, & Richardson, 2009), and RDT reliability in preschool children has previously been reported. In prior analyses of reliability using test–retest, descriptive results (i.e., mean [M] and ± standard deviation [*SD*]) for pretest and retest were 38.43 ± 7.86 and 37.56 ± 9.75 cm ($p = .264$), respectively (Latorre Román et al., 2015). Moreover, prior researchers found an intraclass correlation coefficient (ICC) equal to 0.744 (95% confidence interval [0.836, 0.602]), the Bland–Altman graphic showed limits of agreement (2 *SD*) of 13.8 and −13.6 cm, and the mean of the differences was equal to 0.10 ± 6.87 cm (Latorre Román et al., 2015). In addition, the RDT has also been used in previous studies among school-aged children (Aranha, Saxena, et al., 2017; Fong, Ng, & Chung, 2013; Manna et al., 2014). In this regard, a previous study showed no significant differences between boys and girls in RDT for age groups 6-12 years; in addition, the RDT performance increased with age, and a significant change occurred between six and eight years of age (Aranha, Saxena, et al., 2017).

Despite being a significant indicator of function, behavior, and performance, RT has been infrequently employed in school settings to identify children with slowed motor cognitive processing. We assert that an early identification of delayed RT would help teachers and parents address children's functional deficits and quality of life (Aranha, Saxena, et al., 2017). Yet, to the best of our knowledge, there is no information available about reference values of RDT in preschool children. This study hypothesized no significant gender differences in RDT, but we expected variables, such as age and BMI, to influence a participant's RDT performance, with improved RDT performance with increasing age and worsening of RDT performance with increased BMI. Therefore, the main purpose of this study was to examine age and gender differences in RDT and determine and present reference RDT values for Spanish preschool children.

Method

Participants

A total of 3,741 children participated in this study (1,845 girls and 1,896 boys; M age = 55.93, *SD* = 11.14 months; M BMI = 15.94, *SD* = 1.91 kg/m^2); they were selected from 51 schools in southern Spain. This was a convenience sample selected from a large geographic area (both urban and rural) of Andalusia (Spain). Inclusion criteria were schooling in early childhood and being free from physical or intellectual disabilities. Parents of all child participants voluntarily signed an informed consent form prior to their child's participation in this study. The study was completed in accordance with the norms of the Declaration of Helsinki (2013 version) and was approved by the ethics committee of the University of Jaén (Spain).

Instrumentation. Body height (in cm) was measured with a stadiometer (Seca 222, Hamburg, Germany) and body mass (in kg) with a weighing scale (Seca 899, Hamburg, Germany). BMI was calculated by dividing body mass (kg) by height^2 (m). Waist circumference (WC) was established using a Seca Ergonomic Circumference Measuring Tape SE201 (Seca, Germany). To measure the RT, we used the RDT, which aims to measure the RT and eye-hand coordination. We used a 50- to 60-cm-long ruler and repeated the RDT three times with each hand, determining the average score of each hand for subsequent statistical analysis. The RT conversion is performed using the formula for a body in free fall under the influence of gravity ($d = ½\, gt^2$). The test score was the distance reached, with a lower distance indicating better performance. Regarding time conversion, the test score was the running time, with a longer time corresponding to a poorer performance.

Procedure. We used the following standardized testing procedure for RDT: The child was invited to sit on a chair with their hand kept in the mid-prone position, elbow flexed to 90°, and forearm supported on a table, with the open hand at the edge of the surface. The ruler was suspended vertically by the examiner, such that the 0-cm mark on the ruler coincided with the borders of the fingers (Figure 1). The ruler was then dropped between two fingers without prior intimation, and the subjects were asked to grasp it as quickly as possible. The order of testing of each hand was randomized. The research team conducted a demonstration. The children also performed some familiarization trials for the RDT. The children were encouraged to reach the best score possible. A week later, 84 children (included in the previous data collection) performed the same test (retest).

Data analysis. Data were analyzed using SPSS, v.19.0 for Windows (SPSS Inc., Chicago, IL) and the R statistical program (R Development Core Team, 2016)

Figure 1. Ruler drop test.

with the Generalized Additive Model for Location, Scale and Shape (GAMLSS) package (Rigby & Stasinopoulos, 2006). The statistical significance level was set at $p < .05$. Descriptive data were reported as Ms and *SD*s. Tests of normal distribution and homogeneity (Kolmogorov–Smirnov and Levene's tests) were conducted on all data before analysis. Differences between gender and age groups were analyzed using analysis of variance adjusted by the Bonferroni test. The magnitudes of the differences between values were also interpreted using Cohen's *d* effect size (Cohen, 1988). Effect sizes are reported as: trivial (<0.2), small (0.2–0.49), medium (0.5–0.79), and large (≥ 0.8) (Cohen, 1988). Pearson's correlation analysis was performed between the RDT and the anthropometric variables, adjusting for age and gender. A reliability pretest–posttest analysis was performed using intraclass correlation coefficients (ICCs). According to the classifications proposed by Shrout and Fleiss (1979), a very good correlation is represented by ICC > 90; a good correlation lies between $0.71 < \text{ICC} < 0.90$, a moderate ICC between $0.51 < \text{ICC} < 0.70$, and a poor ICC between $0.31 < \text{ICC} < 0.50$. The percentile curves were calculated as a function of age stratified by gender, using the mbda, mu, sigma, power exponential (LMSP) method, assuming a Box–Cox power exponential distribution, a generalized model of the lambda, mu, sigma (LMS) method. This approach has been implemented in the GAMLSS package in R software (Stasinopoulos & Rigby, 2007).

Results

Table 1 shows these participants' anthropometric characteristics and RDT performances, subgrouped by gender. Boys presented a higher mean BMI than girls, and girls exhibited significantly poorer RT scores in the RDT than did boys when comparing the mean score of both hands and the individual scores of each hand (right and left). Table 2 shows the mean RT performance by both age-group and gender. Girls displayed a significantly poorer performance from the age of 4 years ($p = .032$) to 5 years ($p = .001$) than did same aged boys. In relation to age, for the whole group, the RT performance increased with increasing age from 5 years. Pearson's correlation analysis indicated a weak negative correlation between the RT and age ($r = -.052$, $p = .002$), height ($r = -.111$, $p < .001$), and weight ($r = -.100$, $p < .001$). The 0.4th, 2nd, 10th,

Table 1. Anthropometric Characteristics and RDT Performance According to Sex.

	All ($n = 3{,}741$) Mean (*SD*)	Boys ($n = 1{,}896$) Mean (*SD*)	Girls ($n = 1{,}845$) Mean (*SD*)	*p*	Cohen's *d*
Age (years)	55.93 (11.14)	55.71 (11.11)	56.16 (11.16)	.211	−0.041
Body mass (kg)	19.39 (4.27)	19.63 (4.37)	19.14 (4.16)	<.001	0.114
Body height (cm)	109.18 (8.35)	109.48 (8.41)	108.87 (8.29)	.023	0.073
Body mass index (kg/m^2)	15.94 (1.91)	16.03 (1.93)	15.85 (1.89)	.003	0.099
WC (cm)	56.72 (7.90)	56.86 (7.68)	56.57 (8.11)	.243	0.037
RDT right hand (cm)	33.27 (11.89)	32.56 (11.77)	33.99 (11.97)	<.001	−0.083
RDT left hand (cm)	31.95 (11.19)	31.43 (11.01)	32.49 (11.36)	.004	−0.012
RDT average (cm)	32.43 (10.56)	31.86 (10.40)	33.02 (10.70)	.001	−0.053

Note. *SD* = standard deviation; WC = waist circumference; RDT = ruler drop test.

Table 2. RDT Average by Age Groups and Sex.

Age (years)	All		Boys		Girls			
	n	Mean (*SD*)	*n*	Mean (*SD*)	*n*	Mean (*SD*)	*p*	Cohen's *d*
3	931	32.56 (11.56)$_a$	483	32.43 (11.08)$_a$	448	32.70 (11.26)$_a$	.697	−0.024
4	1,175	33.30 (10.81)$_a$	604	32.66 (10.53)$_a$	571	33.98 (11.07)$_a$	.032	−0.122
5	1,302	32.25 (10.07)$_a$	659	31.29 (9.86)$_{a,b}$	643	33.24 (10.19)$_a$	.001	−0.194
6	329	29.73 (9.35)$_b$	148	29.26 (9.47)$_b$	181	30.12 (9.26)$_b$	.461	−0.092
p (intra group)		<.001		<.001		<.001		

Note. Values with different subscript letters indicate significant differences ($p < .05$) in post hoc analysis Bonferroni. The data are displayed in cm. *SD* = standard deviation; RDT = ruler drop test.

25th, 50th, 75th, 90th, 98th, and 99.6th percentile curves were computed for RDT, averaging the results of both hands, according to gender and age (Table 3, Figures 2 and 3).

Discussion

This study hypothesized no significant gender differences in RDT, but we expected variables, such as age and BMI, to influence a participant's RDT performance such that RDT performance would improve with increasing age and BMI. However, our results unexpectedly revealed that RDT performance differed between 4- and 5-year-old boys and girls, with girls exhibiting a poorer performance than boys. There were no significant gender differences between the genders for 3-year-olds. Few studies have focused on preschool children over this age range. Nonetheless, a previous study showed that males had a significantly faster mean RT than females across the life span (Dykiert, Der, Starr, & Deary, 2012). Surnina and Levedeva (2001) found that even in preschool children, gender dimorphism manifested itself in the reaction rate, with quick reactions occurring more often in boys than girls. Conversely,

Table 3. Percentiles Values of RDT Average in Boys and Girls.

Age (months)	Percentile	0.4	2	10	25	50	75	90	98	99.6
36	Boys	7.59	11.02	16.61	22.39	30.67	39.34	45.91	52.80	57.41
	Girls	8.17	11.56	17.05	22.51	30.04	38.41	45.76	54.81	61.66
42	Boys	9.59	12.86	18.24	23.82	31.89	40.68	47.75	55.64	61.17
	Girls	8.71	12.53	18.54	24.34	32.12	40.62	48.09	57.30	64.29
48	Boys	8.49	12.47	18.60	24.44	32.25	40.45	47.20	55.00	60.62
	Girls	8.94	13.06	19.39	25.32	33.03	41.34	48.64	57.69	64.57
54	Boys	8.06	12.63	19.31	25.21	32.47	40.06	46.79	55.20	61.65
	Girls	9.09	13.50	20.10	26.10	33.68	41.73	48.82	57.65	64.39
60	Boys	9.60	13.73	19.86	25.25	31.80	38.91	45.77	55.12	62.82
	Girls	9.11	13.75	20.51	26.46	33.79	41.46	48.26	56.75	63.26
66	Boys	11.29	14.47	19.42	24.11	30.31	37.36	44.17	53.45	61.15
	Girls	8.86	13.60	20.31	26.04	32.91	40.02	46.34	54.28	60.40
72	Boys	10.51	13.44	18.07	22.63	28.92	35.89	42.01	49.51	55.20
	Girls	8.36	13.03	19.47	24.82	31.05	37.42	43.12	50.34	55.91
78	Boys	7.95	11.15	16.07	20.86	27.38	34.06	39.19	44.70	48.45
	Girls	7.55	11.95	17.84	22.60	28.00	33.46	38.38	44.65	49.52

Note. The data are displayed in cm. RDT = ruler drop test.

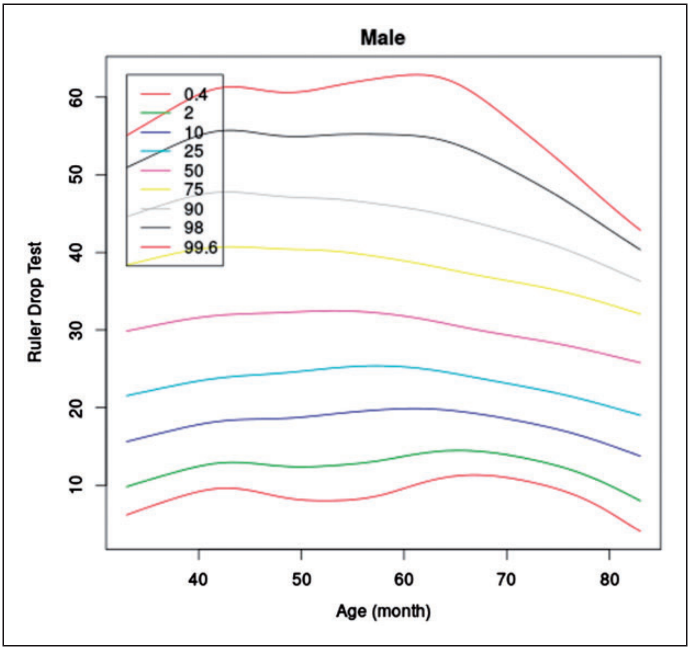

Figure 2. Percentile curves for RDT (cm) for boys.

Aranha, Saxena, et al (2017) found no significant gender differences in RDT in children aged 6-12 years, which can be explained by the fact that, in this study, there were no significant differences in BMI between genders.

Regarding age, the RT values decreased with increasing age, beginning only from five years of age. Our findings add to past research, showing that at age 5-6 years, RT decreased (Surnina & Lebedeva, 2001). Likewise, Bucsuházy and Semela (2017) noted significant differences between children 3-5 and 6-7 years old. In addition, Aranha, Saxena, et al., 2017 found that RDT values were similar in children 6-8 and 10-12 years old, while significant differences emerged from 8-10 years old. Therefore, these systems mature in childhood and, consequently, a shorter and less variable RT is part of typical development (Klotz et al., 2012). Consistent with Kiselev (2015), we assume that the age-related differences in processing speed can be understood in relation to the heterochronicity of child brain development and the specific mechanisms related to brain maturation.

In contrast, the influences of anthropometric characteristics, such as body mass, body height, BMI, and WC, on the RT in preschool children are less well understood. Several studies demonstrated that obesity and being overweight reduced RT performance (Gentier et al., 2013; Skurvydas

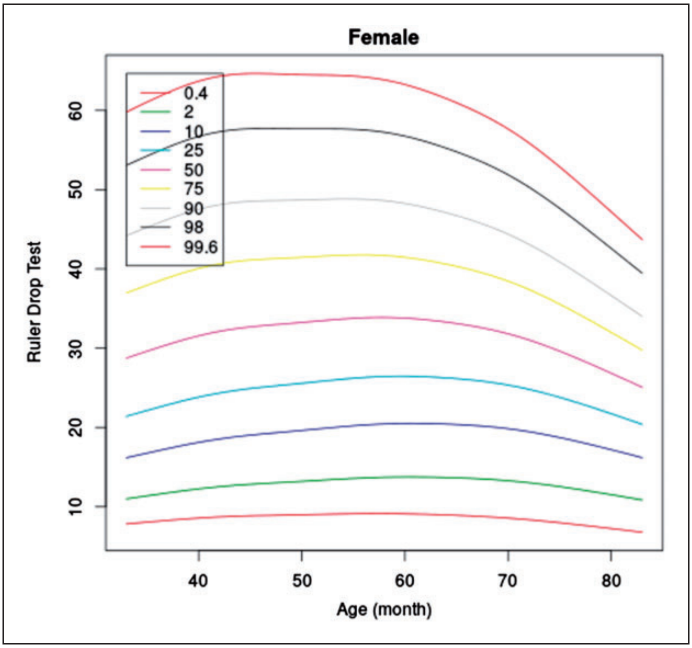

Figure 3. Percentile curves for RDT (cm) for girls.

et al., 2009). This study suggests that RDT in healthy preschool children aged 3-6 years are correlated with parameters of physical growth, such as body mass and body height, although Pearson's values were very low. Similar results were reported by Aranha, Saxena, et al. (2017) who found moderate correlations between RDT and body height ($r = -.33$) and body mass ($r = -.28$) in school children. Moreover, in this study, no correlations between BMI, WC, and RDT were noted, concurring with recent studies that investigated the relationship between RT and weight status in children (Aranha, Saxena, et al., 2017; Esmaeilzadeh, 2014; Moradi & Esmaeilzadeh, 2017). Finally, this study provides age- and gender-adjusted reference values for RDT, in Spanish preschool children.

The main limitation of this study was its cross-sectional design. Following children over time in longitudinal research would provide further needed data regarding time-related developmental changes as affected by other variables in individual children. However, a strength of this study was the large population sample we gathered. Of course, this study might also have been improved by the collection of additional relevant data that might affect RT development and manifestation in preschool children.

Conclusion

This study revealed unexpected gender differences (with boys superior at ages 4–5 years) and expected age differences in RT performance, and we provide reference values for the RDT that now allow future individual child comparisons on this simple RT task. Advantages of the RDT include that it requires no training and has a relatively short duration and that instrument requirements are simple and accessible (Aranha, Saxena, et al., 2017). The RDT may now be more frequently used for monitoring RT development in preschoolers, with percentile values of this study providing reference values for teachers and coaches working with children aged 3-6 years.

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Declaration of Conflicting Interests

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Human Subjects Approval Statement

The study was completed in accordance with the norms of the Declaration of Helsinki (2013 version) and was approved by the Ethics Committee of the University of Jaén (Spain).

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